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Park et al.

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(54) **QUERY ENGINE FOR BUILDING MANAGEMENT SYSTEMS**

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(51) **Int. Cl.**
G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/30693*** (2013.01); ***G06F 17/3043*** (2013.01); ***G06F 17/30557*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/30864; G06F 17/30867; G06F 17/30991
USPC 707/4, 100, 3, 746, 102, 805, 748, 203
See application file for complete search history.

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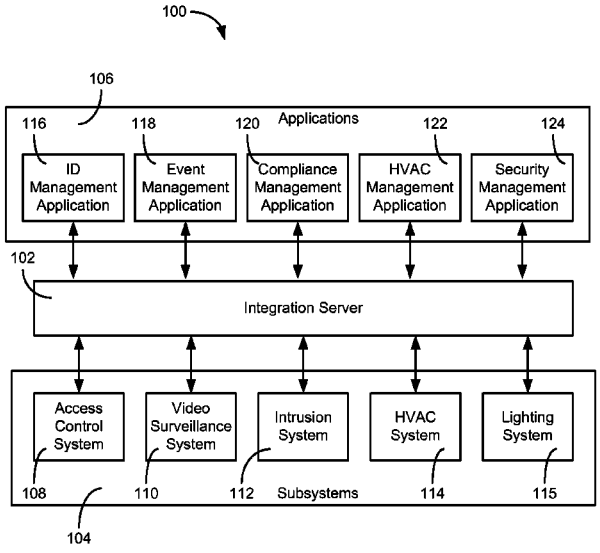
(57) **ABSTRACT**

A computer-implemented system for facilitating cross-subsystem queries of a plurality of building automation subsystems includes a first database storing a logical model for a building automation system. The system further includes a second database storing information for the plurality of building automation subsystems. The second database relates information for the plurality of building automation subsystems based on the logical model of the first database. The system also includes a query engine configured to decompose a cross-subsystem query received from an application into a plurality of subsystem queries using the information of the second database.

20 Claims, 10 Drawing Sheets



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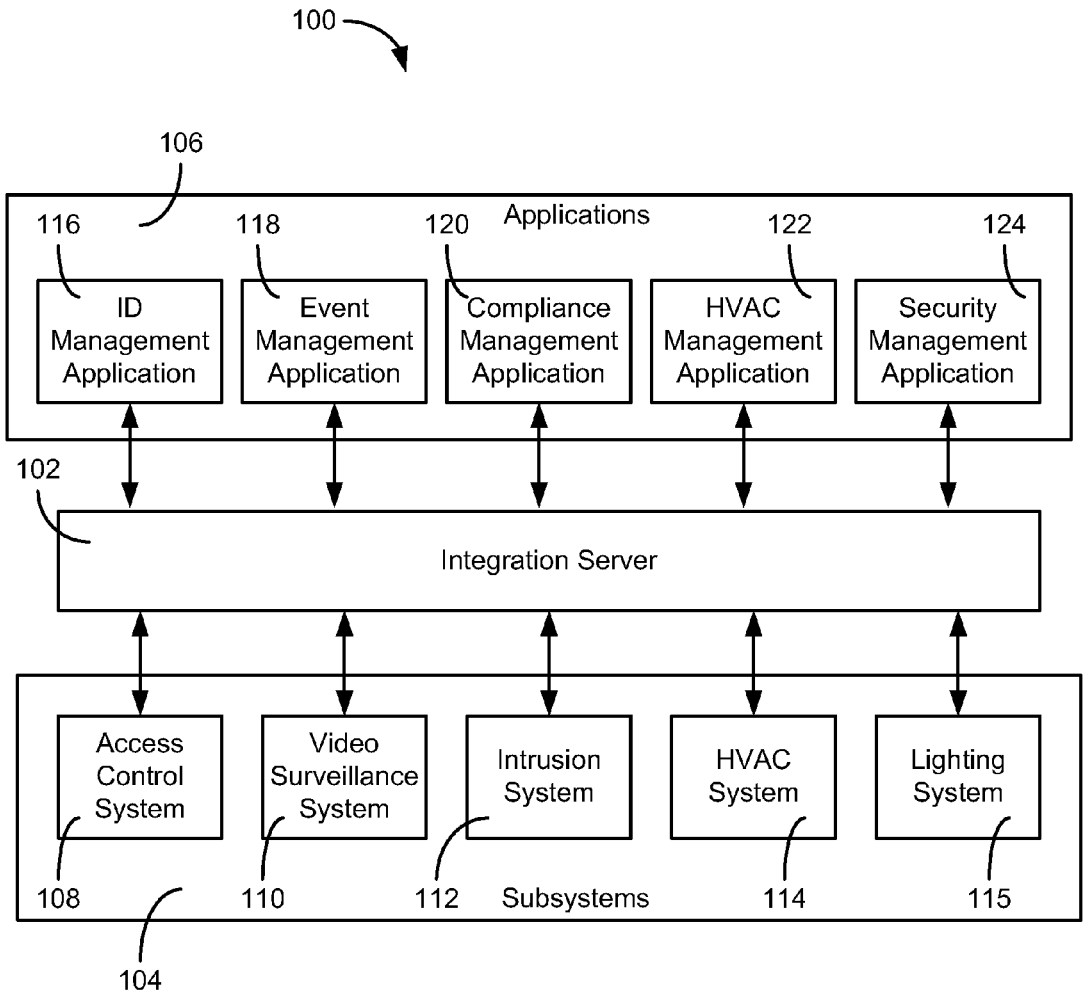

100
106
Applications
116
118
120
122
124
ID Management Application
Event Management Application
Compliance Management Application
HVAC Management Application
Security Management Application
102
Integration Server
Access Control System
Video Surveillance System
Intrusion System
HVAC System
Lighting System
108
110
112
Subsystems
114
115
104

FIG. 1

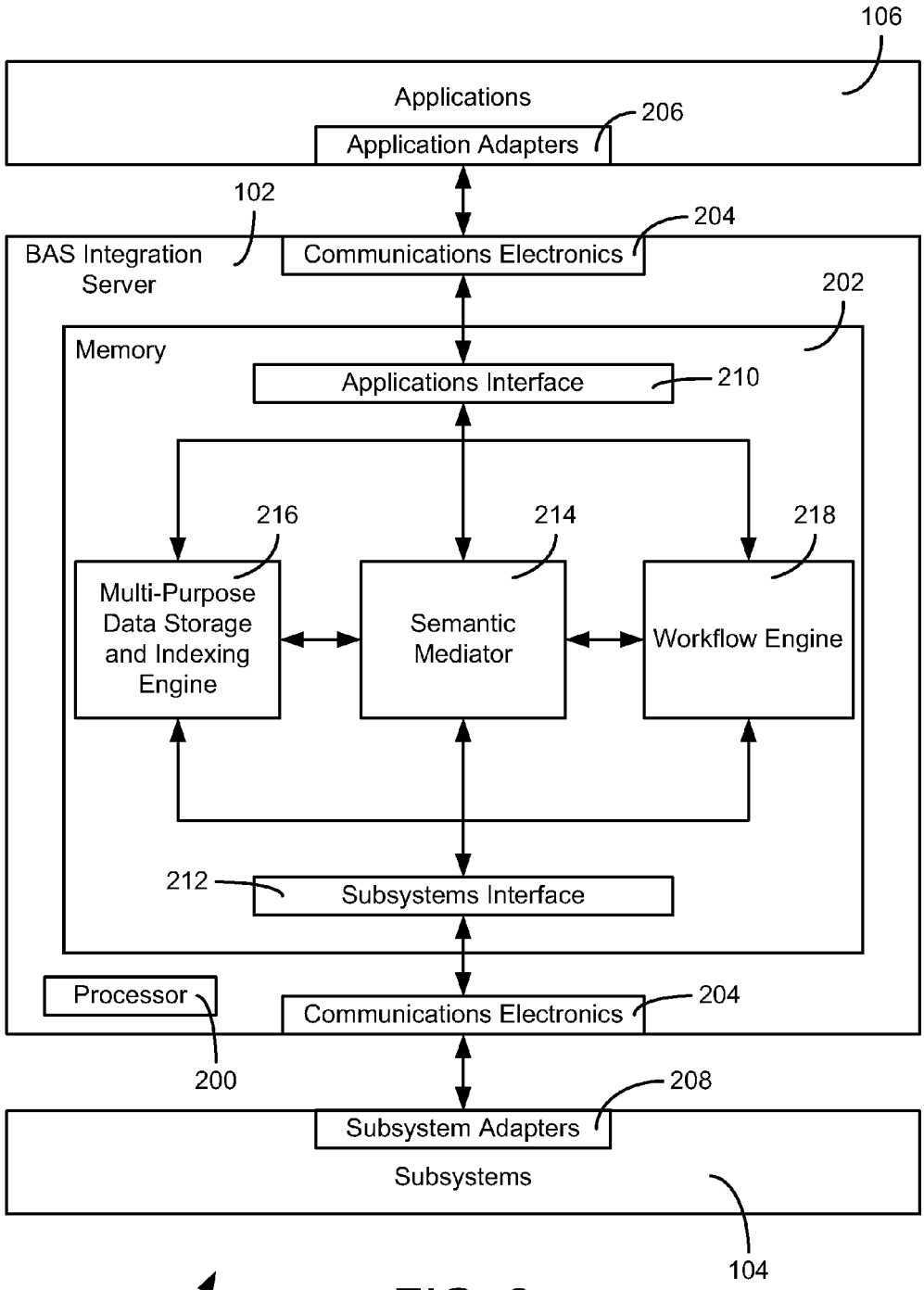

106
Applications
206
Application Adapters
102
204
BAS Integration Server
Communications Electronics
202
Memory
Applications Interface
210
216
214
218
Multi-Purpose Data Storage and Indexing Engine
Semantic Mediator
Workflow Engine
212
Subsystems Interface
Processor
Communications Electronics
204
200
208
Subsystem Adapters
Subsystems
104
100

FIG. 2

FIG. 3

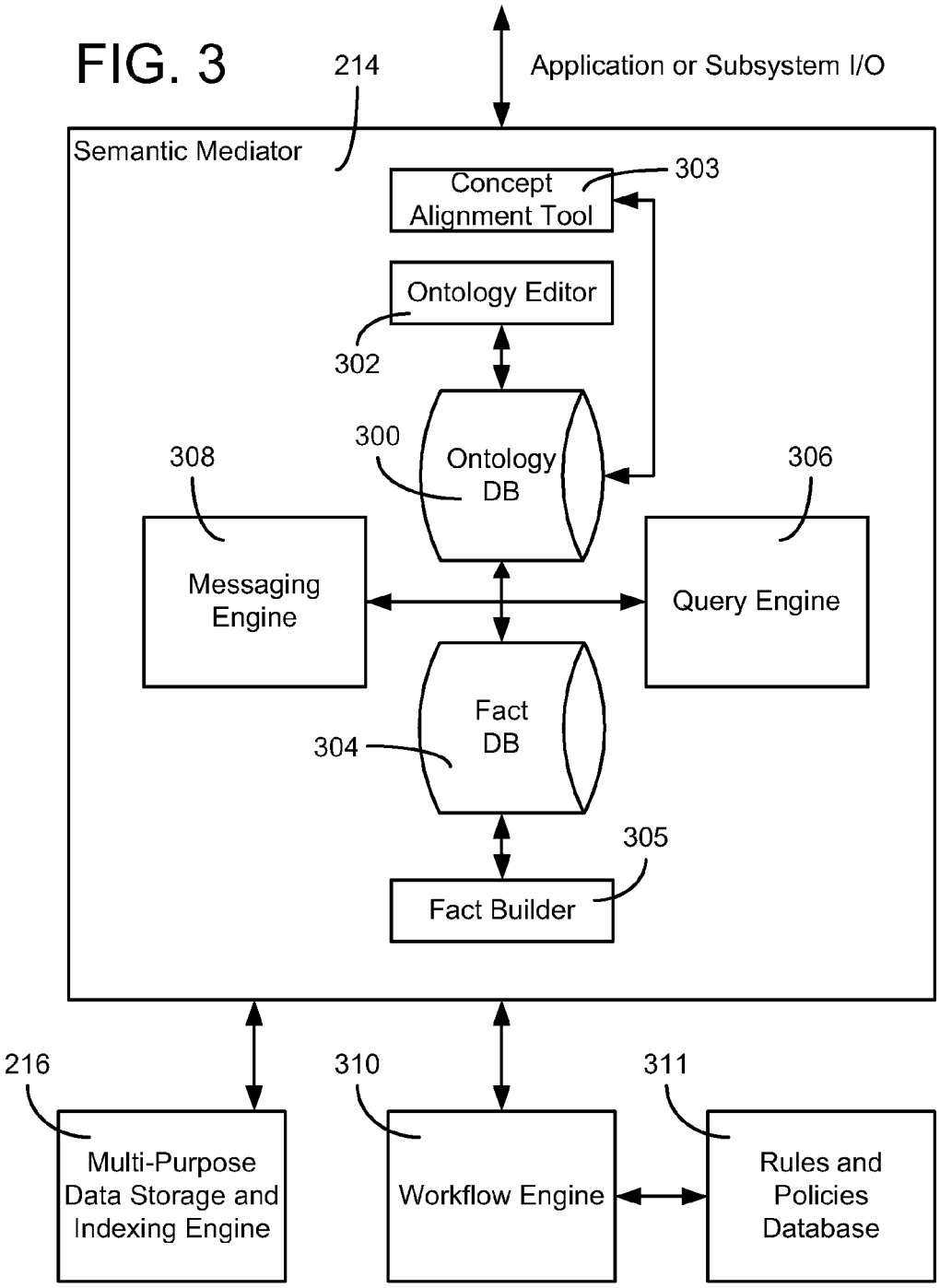
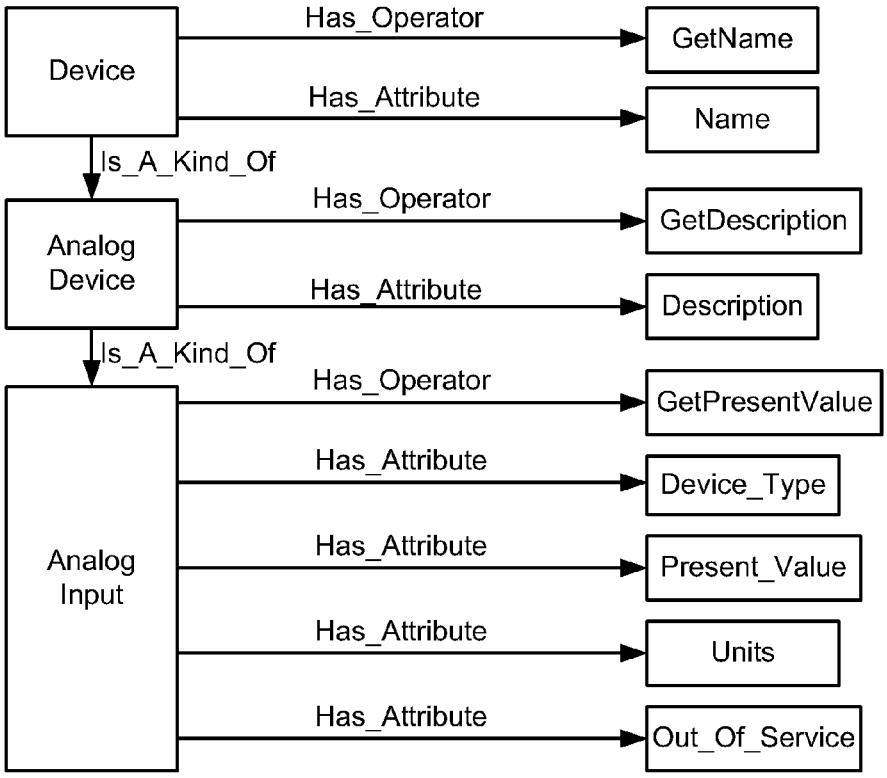

214
Application or Subsystem I/O
Semantic Mediator
303
Concept Alignment Tool
Ontology Editor
302
300
Ontology DB
308
306
Messaging Engine
Query Engine
Fact DB
304
305
Fact Builder
216
310
311
Multi-Purpose Data Storage and Indexing Engine
Workflow Engine
Rules and Policies Database

FIG. 4A



TblConcepts	
1	Φ
2	Device
3	Analog Device
4	Analog Input

Is_A_Kind_Of	
2	1
3	2
4	3

TblAttribute	
1	Name
2	Description
3	Device_Type
4	Present_Value
5	Out_Of_Service
6	Units

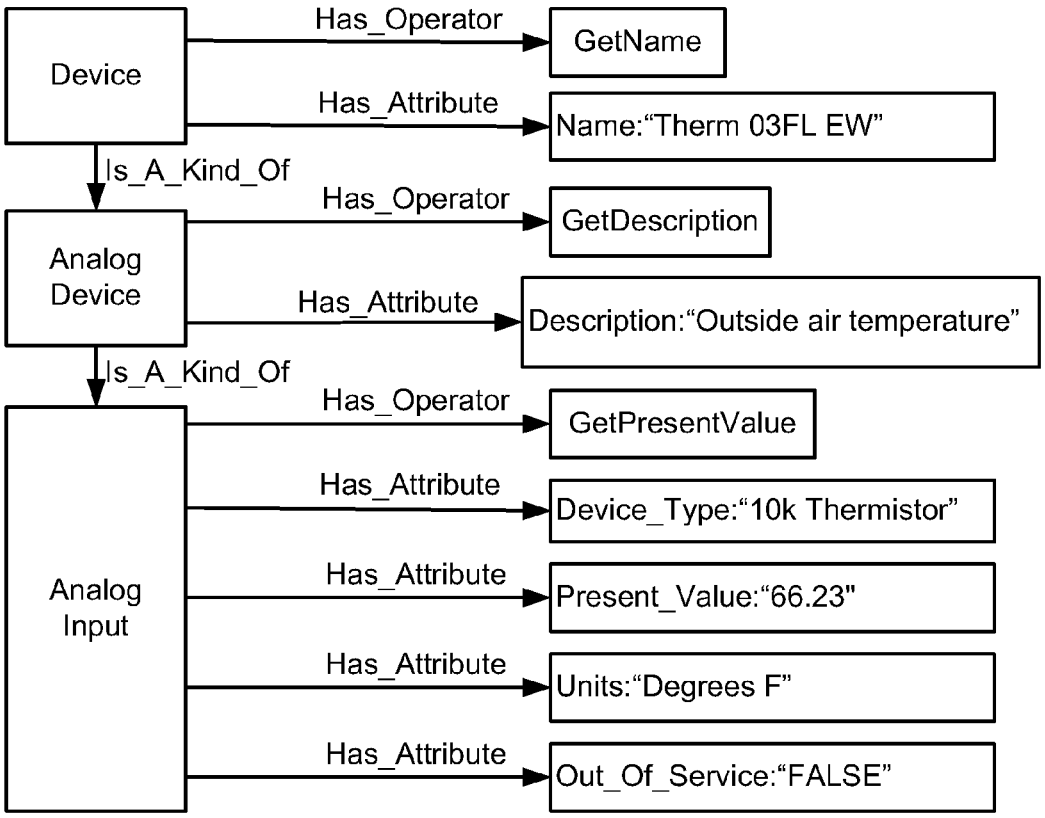
Has_Attribute	
2	1
3	2
4	3
4	4
4	5
4	6

TblOperation	
1	GetName
2	GetDescription
3	GetPresentValue

Has_Operator	
2	1
2	2
3	3

FIG. 4B

FIG. 5A



Fact DB

Logical Type	Instance Value	Subsystem Hashed ID
1→2→3→4#Device_Type	10k Thermistor	
1→2→3→4#Present_Value	66.23	
1→2→3→4#Units	F	
1→2→3→4#Out_Of_Service	FALSE	... Hash Values ...
1→2#Name	Therm 03FL EW	
1→2→3#Description	Outside air temperature	
....	...	

FIG. 5B

FIG. 5C

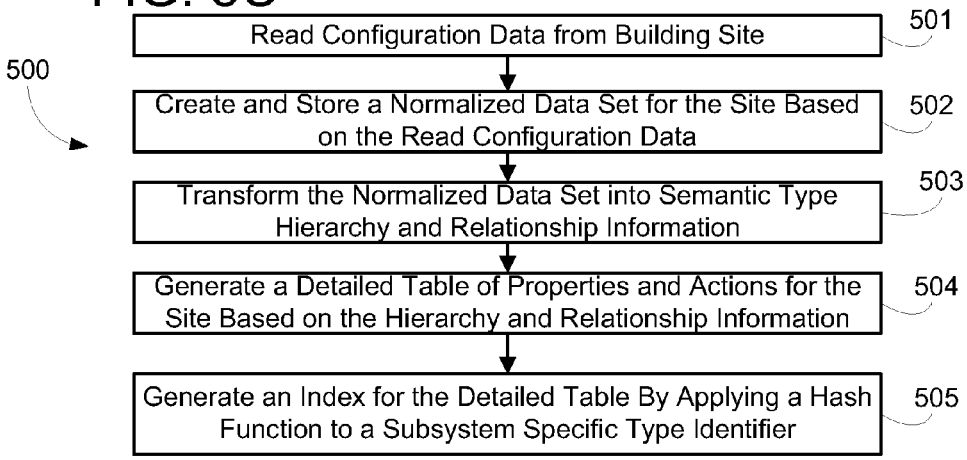
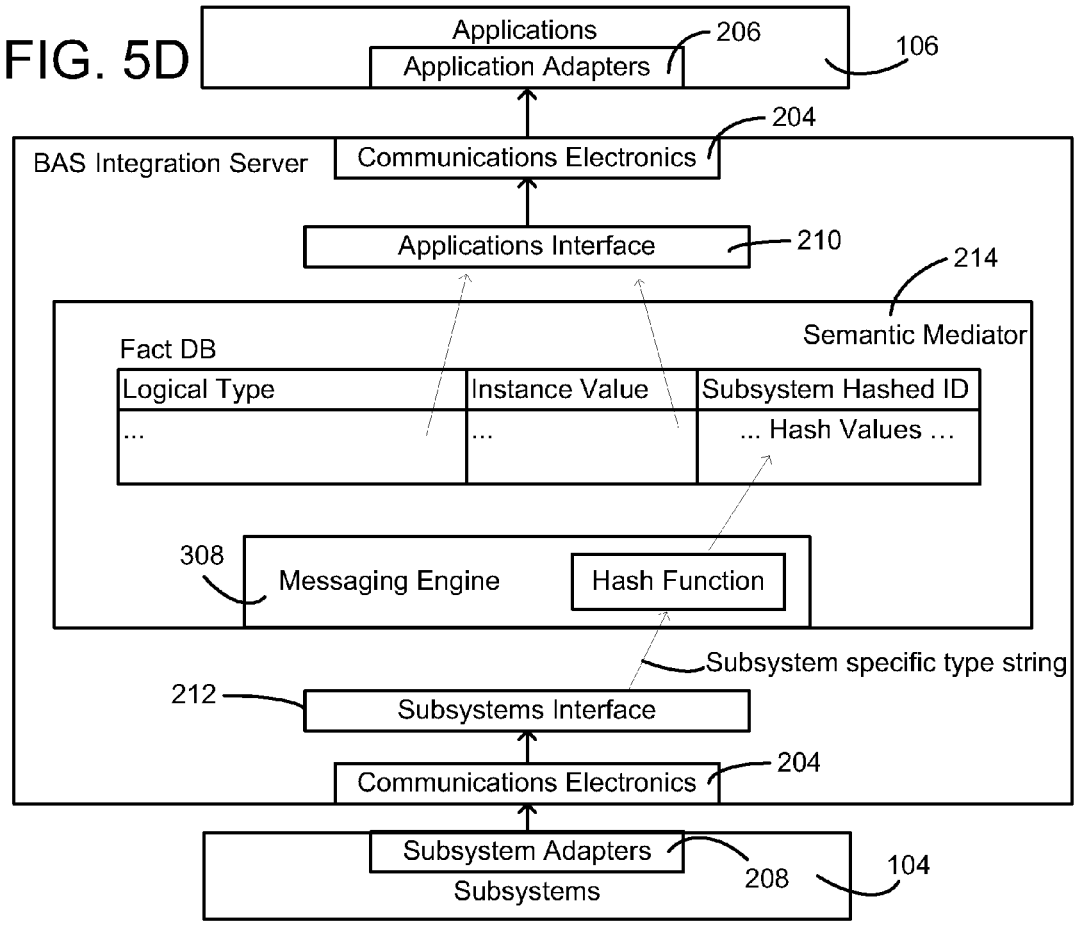

500
Read Configuration Data from Building Site
501
Create and Store a Normalized Data Set for the Site Based on the Read Configuration Data
502
Transform the Normalized Data Set into Semantic Type Hierarchy and Relationship Information
503
Generate a Detailed Table of Properties and Actions for the Site Based on the Hierarchy and Relationship Information
504
Generate an Index for the Detailed Table By Applying a Hash Function to a Subsystem Specific Type Identifier
505

FIG. 5D


Applications
Application Adapters
206
106
204
BAS Integration Server
Communications Electronics
Applications Interface
210
214
Semantic Mediator
Fact DB
Logical Type
Instance Value
Subsystem Hashed ID
...
...
... Hash Values ...
308
Messaging Engine
Hash Function
Subsystem specific type string
212
Subsystems Interface
204
Communications Electronics
Subsystem Adapters
208
104
Subsystems

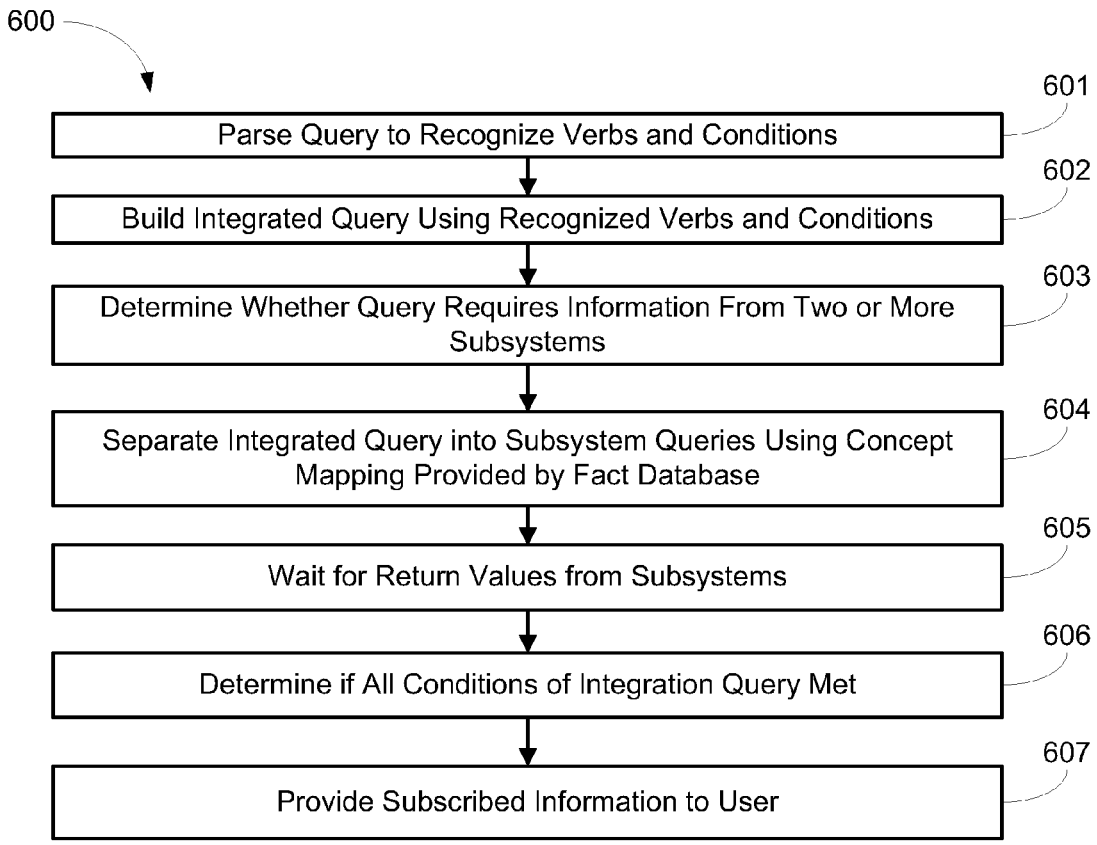

600
601
Parse Query to Recognize Verbs and Conditions
602
Build Integrated Query Using Recognized Verbs and Conditions
603
Determine Whether Query Requires Information From Two or More Subsystems
604
Separate Integrated Query into Subsystem Queries Using Concept Mapping Provided by Fact Database
605
Wait for Return Values from Subsystems
606
Determine if All Conditions of Integration Query Met
607
Provide Subscribed Information to User

FIG. 6A

6-1

Location ID	Location Name
01	Building 1
0101	Floor 1
0102	Floor 2
0103	Floor 3
0101101	Room 101
...	...

6-2

Parent ID	Location Name
01	0101
0101	0101101
0101	0101121
0101	0101122
0101	0101123
0102	0102102
...	...

Location ID	Tags
0101101	Office
0101121	Supplies
0101122	Janitorial
0101123	Kitchenette
0101102	Conference
0101102	Office, Executive
...	...

6-4

Location ID	Point ID
0101101	ADX-1:NAE01/FC-1.011045FEC.ZN-T
0101102	ADX-1:NAE01/FC-2.011045FEC.ZN-T
...	...

6-3

FIG. 6B

Q1.1 = SELECT “Location ID” FROM “Table 6-1” WHERE tag = “Executive”

Q1.2 = SELECT “Location ID” FROM Table 6-2 WHERE “Parent ID” in Q2.1

Q1.3 = SELECT “Point ID” FROM Table 6-3 WHERE ((“Point ID” like “%ZN-T%”) AND (“Location ID” in Q1.1 or Q1.2)

Q2 = SELECT * FROM events WHERE (((“Point ID” in Q1.3) AND (event.priority > 40)) AND (event.temperature > comfort.highlimit))

FIG. 6C

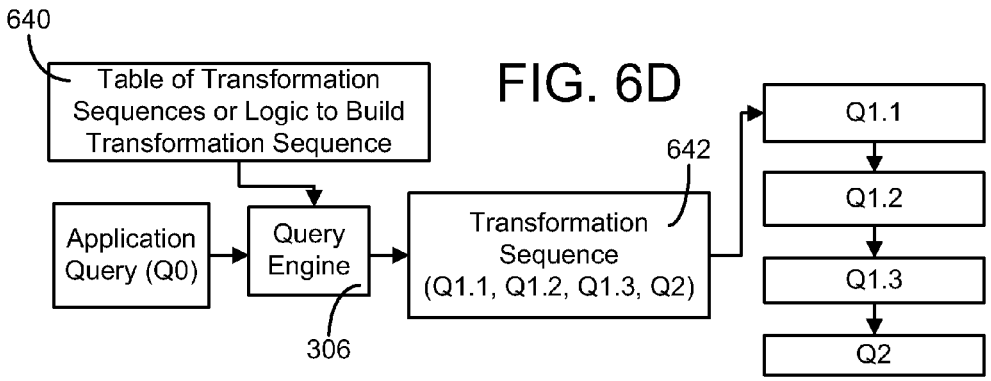


FIG. 6D

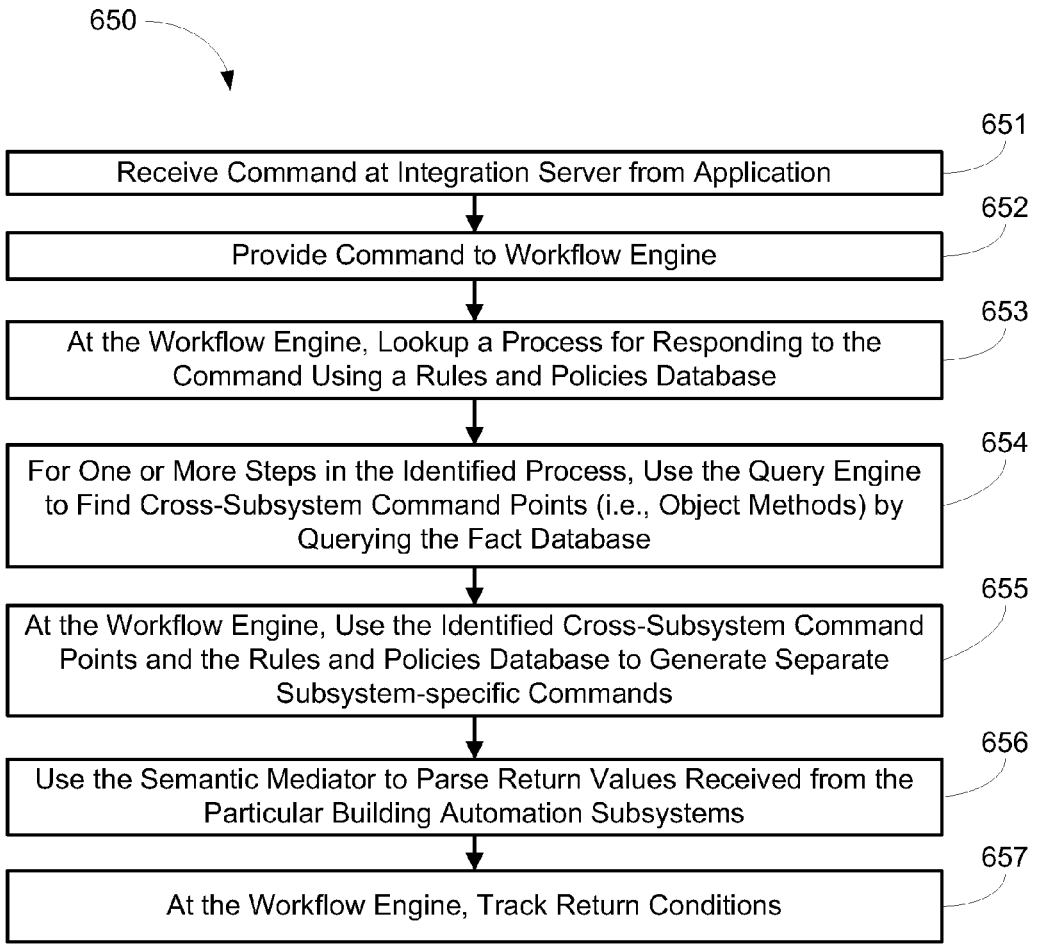
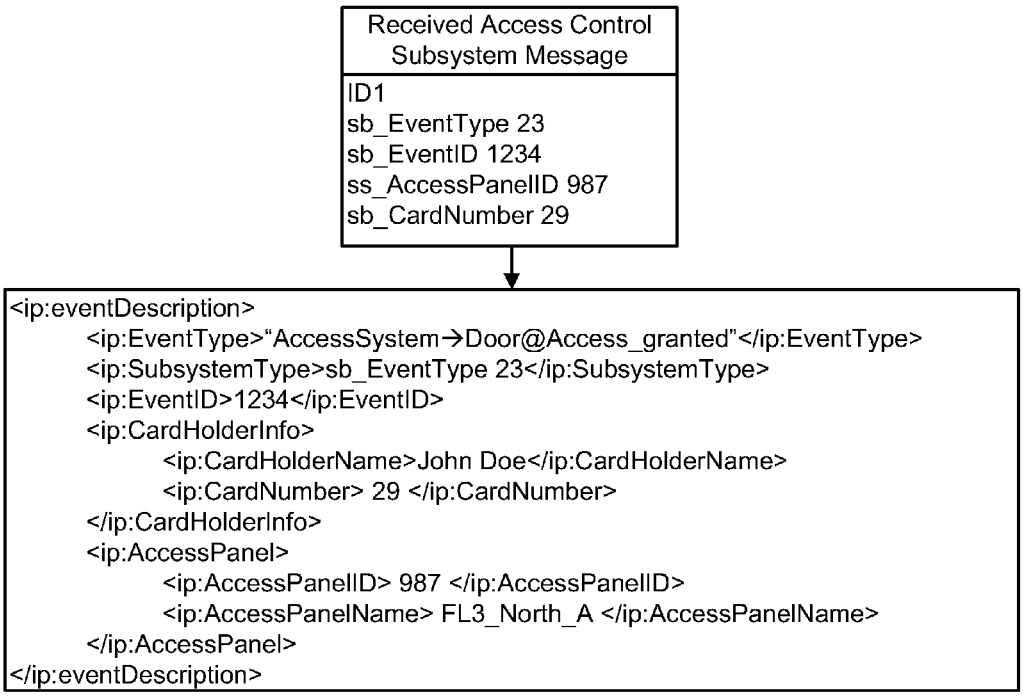

650
651
Receive Command at Integration Server from Application
652
Provide Command to Workflow Engine
653
At the Workflow Engine, Lookup a Process for Responding to the Command Using a Rules and Policies Database
654
For One or More Steps in the Identified Process, Use the Query Engine to Find Cross-Subsystem Command Points (i.e., Object Methods) by Querying the Fact Database
655
At the Workflow Engine, Use the Identified Cross-Subsystem Command Points and the Rules and Policies Database to Generate Separate Subsystem-specific Commands
656
Use the Semantic Mediator to Parse Return Values Received from the Particular Building Automation Subsystems
657
At the Workflow Engine, Track Return Conditions

FIG. 6E


Received Access Control Subsystem Message
ID1
sb_EventType 23
sb_EventID 1234
ss_AccessPanelID 987
sb_CardNumber 29
<ip:eventDescription>
<ip:EventType>"AccessSystem→Door@Access_granted"</ip:EventType>
<ip:SubsystemType>sb_EventType 23</ip:SubsystemType>
<ip:EventID>1234</ip:EventID>
<ip:CardHolderInfo>
<ip:CardHolderName>John Doe</ip:CardHolderName>
<ip:CardNumber> 29 </ip:CardNumber>
</ip:CardHolderInfo>
<ip:AccessPanel>
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</ip:eventDescription>

FIG. 7A

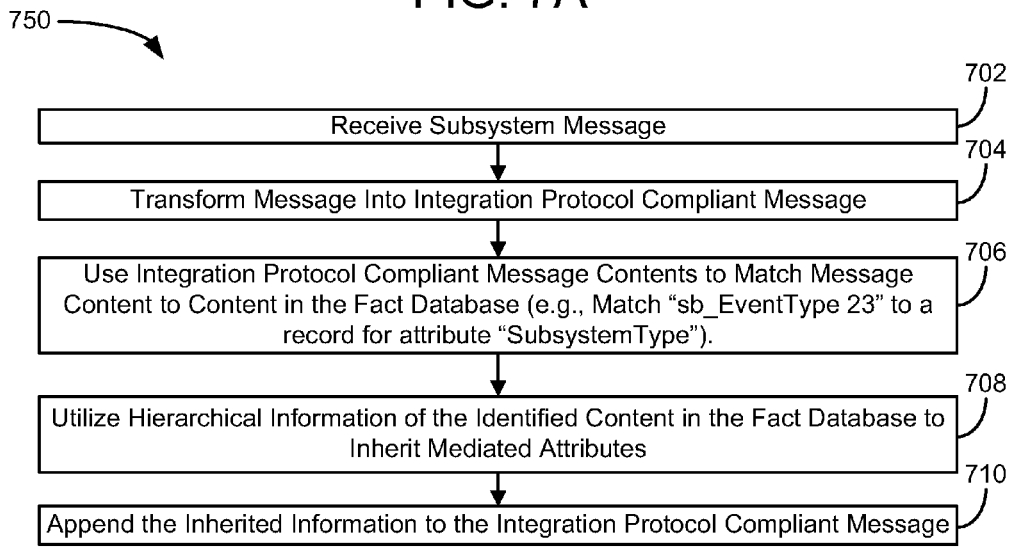
750
702
Receive Subsystem Message
704
Transform Message Into Integration Protocol Compliant Message
706
Use Integration Protocol Compliant Message Contents to Match Message Content to Content in the Fact Database (e.g., Match "sb_EventType 23" to a record for attribute "SubsystemType").
708
Utilize Hierarchical Information of the Identified Content in the Fact Database to Inherit Mediated Attributes
710
Append the Inherited Information to the Integration Protocol Compliant Message

FIG. 7B

QUERY ENGINE FOR BUILDING MANAGEMENT SYSTEMS

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a Continuation of U.S. application Ser. No. 12/831,866, filed Jul. 7, 2010, incorporated herein by reference in its entirety.

BACKGROUND

The present invention relates generally to the field of building management systems. The present invention more particularly relates to systems and methods for archiving and retrieving data in a building automation system.

Building automation systems are, in general, hardware and/or software systems configured to control, monitor, and manage devices in or around a building or building area. BAS subsystems or devices can include heating, ventilation, and air conditioning (HVAC) subsystems or devices, security subsystems or devices, lighting subsystems or devices, fire alerting subsystems or devices, elevator subsystems or devices, other devices that are capable of managing building functions, or any combination thereof.

As BAS systems become more complicated or as a building is upgraded to include different types or versions of BAS subsystems, system integration issues become challenging and difficult to address. For example, conventional BAS subsystems have difficulty exchanging information due to protocol differences or other incompatibilities. Queries or commands that require information from multiple subsystems are difficult to implement.

SUMMARY

One embodiment of the invention relates to a computer-implemented system for facilitating cross-subsystem queries of a plurality of building automation subsystems. The system includes a first database storing a logical model for a building automation system. The system further includes a second database storing information for the plurality of building automation subsystems. The second database relates information of the plurality of building automation subsystems based on the logical model of the first database. The system further includes a query engine configured to decompose a cross-subsystem query received from an application into a plurality of subsystem queries using the information of the second database.

The first database may be an ontology database and the second database may be a fact database. The query engine may utilize the fact database to determine ordering for the subsystem queries. In some exemplary embodiments the query engine may retrieve the subsystem queries from sets of pre-built and pre-stored subsystem queries. In yet other exemplary embodiments the query engine may build the subsystem queries by processing the cross-subsystem query. The query engine may store the plurality of subsystem queries and provides an updated message to the application originating the cross-subsystem query when results of the cross-subsystem query change. The query engine may provide the changed results through a messaging engine that uses the query result to build a message for the application. The messaging engine may append hierarchical information from the second database to the message for the application. The message for the application may include at least one string (e.g., a projected semantic type string) representing the hierarchical information associated with the message contents and based on the logical model of the first database.

Another embodiment of the invention relates to a computer-implemented method for facilitating cross-subsystem queries of a plurality of building automation subsystems. The method includes receiving a cross-subsystem query from an application. The method further includes recognizing the cross-subsystem query as requiring access to more than one of the plurality of building automation subsystems. The method yet further includes decomposing the cross-subsystem query into a plurality of subsystem queries using a database system that relates information for the plurality of building automation subsystems according to a cross-subsystem hierarchical model.

The method may further include determining ordering for the subsystem queries using the hierarchical model. retrieving the subsystem queries from sets of pre-built and pre-stored subsystem queries. The method may yet further include building the subsystem queries by processing the cross-subsystem query. The method may also include storing the plurality of subsystem queries and providing an updated message to the application originating the cross-subsystem query when results of the cross-subsystem query change. In some embodiments the method also includes providing the changed results to a messaging engine that uses the query result to build a message for the application. The method may also include appending hierarchical information from the database system to the message for the application. Appending the hierarchical information may include appending at least one string representing the hierarchical information associated with the message contents. The string may be a projected semantic type string relating to the subsystem type of the message contents. The plurality of building automation subsystems may be disparately protocolled.

Another embodiment of the invention relates to a computer-implemented system for facilitating communication between a plurality of disparate building automation subsystems and a plurality of applications. The system includes an ontology database storing a logical model for a building automation system. The system further includes a fact database storing information for a particular building automation system, wherein the ontology database relates information for the plurality of disparate building automation subsystems in a standardized fashion based on the logical model of the ontology database. The system yet further includes a messaging engine configured to receive a message from one of the disparate building automation subsystems and for one of the plurality of applications, wherein the messaging engine is configured to use the information in the fact database to transform the message into a standard format, to append hierarchical information to the transformed message, and to provide the transformed message to the one of the plurality of applications.

Another embodiment relates to a computer-implemented method for facilitating communication between a plurality of disparate building automation subsystems and a plurality of applications. The method includes storing a logical model for a building automation system in an ontology database. The method further includes storing information for a particular building automation system in a fact database. The fact database relates information for the plurality of disparate building automation subsystems in a standardized fashion based on the logical model of the ontology database. The method further includes receiving a message from one of the disparate building automation subsystems and for one of the plurality of applications at a messaging engine. The method yet further includes using the information in the fact database to trans-

form the message into a standard format. The method also includes appending the hierarchical information to the transformed message and providing the transformed message to the one of the plurality of applications.

Alternative exemplary embodiments relate to other features and combinations of features as may be generally recited in the claims.

BRIEF DESCRIPTION OF THE FIGURES

The disclosure will become more fully understood from the following detailed description, taken in conjunction with the accompanying figures, wherein like reference numerals refer to like elements, in which:

FIG. **1** is a block diagram of a BAS including an integration server, according to an exemplary embodiment;

FIG. **2** is a block diagram showing a more detailed view of the integration server of FIG. **1**, according to an exemplary embodiment;

FIG. **3** is a more detailed block diagram of the semantic mediator of FIG. **2**, according to an exemplary embodiment;

FIG. **4**A is a directed graph representing a model of a theoretical BAS, according to an exemplary embodiment;

FIG. **4**B is a table set that may be stored in the ontology database of FIG. **3** and representing the directed graph of FIG. **4**A, according to an exemplary embodiment;

FIG. **5**A illustrates a particular instance of the directed graph shown in FIG. **4**A, according to an exemplary embodiment;

FIG. **5**B is an example of a fact database portion having contents representing the instance of FIG. **5**A, according to an exemplary embodiment;

FIG. **5**C is a flow chart of a process for creating a BAS integration framework according to an exemplary embodiment;

FIG. **5**D is a partial block diagram of the integration server of FIG. **1**, according to an exemplary embodiment;

FIG. **6**A is a flow chart of a process for receiving and servicing a query requiring information from multiple systems, according to an exemplary embodiment;

FIG. **6**B is an exemplary set of tables stored in a fact database, according to an exemplary embodiment;

FIG. **6**C illustrates four queries that may be used to process a subsystem query using the table set of FIG. **6**B, according to an exemplary embodiment;

FIG. **6**D is a block diagram of a system for executing the queries of FIG. **6**C, according to an exemplary embodiment;

FIG. **6**E is a flow chart of a process for implementing a cross-subsystem command, according to an exemplary embodiment.

FIG. **7**A is an example of a messaging transformation conducted by the messaging engine of FIG. **3**, according to an exemplary embodiment; and

FIG. **7**B is a flow chart of a process for achieving the transformation shown in FIG. **7**A, according to an exemplary embodiment.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

Referring to FIG. **1**, a block diagram of a BAS **100** including an integration server **102** is shown, according to an exemplary embodiment. BAS **100** is shown to include a plurality of subsystems **104**. In a conventional BAS each of subsystems **104** includes its own software applications configured to control the subsystem or configured to provide user interfaces for user interaction with the subsystem. Conventional software applications typically allow for discrete operations or monitoring of the subsystem but typically do not provide for cross-subsystem control.

One embodiment of the present application relates to a computer-implemented system for facilitating communication between a plurality of building automation subsystems (e.g., disparately protocolled BAS subsystems) and a plurality of applications. The present invention advantageously allows BAS applications to utilize cross-subsystem data and cross-subsystem interaction to provide for improved control and improved user experiences.

Subsystems **104** are shown to include access control system **108**, video surveillance system **110**, intrusion system **112**, HVAC system **114**, and lighting system **115**. Fewer, additional, or alternative subsystems may be included in BAS **100**. Access control system **108** may include access card readers, biometric scanners, or other readers configured to obtain information about a user. A computer system of access control system **108** can check the obtained user information against access permissions or other data, record user accesses, or conduct other access control activities. Video surveillance system **110** may include any number of cameras (e.g., analog, digital, etc.) connected to video recorders, object or event recognition processors, or other processing electronics or computer systems configured to use video information. Intrusion system **112** may include a network of sensors configured to provide alarms or otherwise change states if entry to a building or area has been forced. For example, intrusion system **112** can include any number of motion detectors, infrared sensors, glass break detectors, door contact sensors, and the like. HVAC system **114** includes any number of devices, controllers, and connections configured to allow for the control of heating, ventilation, or air conditioning in a building space. For example, HVAC system **114** may include a chiller, a boiler, any number of air handling units, economizers, field controllers, master controllers, actuators, temperature sensors, or other devices for controlling the temperature within a building space. Lighting system **115** can include any number of lights, relays connected to controllers, lighting sensors, dimmers, or other devices configured to controllably adjust the amount of the light provided to a building space. It should be noted that subsystems **104** may include more than one of any given type of subsystem. For example, in an exemplary embodiment multiple HVAC subsystems may be used to provide control to the same building or to the same collection of buildings (e.g., an old building may have a first HVAC system while a new building has a second HVAC system). Further, the subsystems may communicate according to disparate protocols. For example, a first HVAC subsystem may not be configured to communicate with a second HVAC subsystem or other of the building subsystems.

BAS **100** is further shown to include applications **106**. Applications **106** include identification (ID) management application **116**, event management application **118**, compliance management application **120**, HVAC management application **122**, and security management application **124**. Fewer, additional, or alternative applications may be included in BAS **100**. In some embodiments all of applications **106** are integrated into a single application suite or integrated within a single system. Applications **106** may be thick clients running almost entirely on remote computers (computers remote from integration server **102**). Applications **106** may alternatively be thin clients where the logic for the applications is hosted on a server (e.g., integration server **102**, a GUI server, a web server, or another server) and the client is used primarily for user input and output (e.g., GUI display tasks).

ID management application **116** is an application that allows the creation and use of a single user credential that propagates across or can be used across physical security, logical (information technology) security, and business systems. ID management application **116** can be used to control where users can go in a building or campus or what information the users can access (e.g., via electronic devices). ID management application **116** can track where a user has been and where a user is currently. ID management application **116** may include user interfaces for configuring physical badges, managing visitors, providing users with self-service (e.g., updating contact information for the user), or other user interfaces regarding users, access, or location.

Event management application **118** may be an application that integrates data from access control system **108**, video surveillance system **110**, intrusion system **112**, HVAC system **114**, and lighting system **115** to provide a single integrated "command center" user interface. Data from subsystems **104** can be combined on user interfaces to provide a common operating picture. The combination of pertinent data across multiple systems on a single user interface can advantageously provide for more complete situational awareness or support advanced cross-subsystem process automation features.

Compliance management application **120** may be an application that utilizes data from subsystems **104** to check for compliance relative to internal or external policies. If data is available for combination "in real time," a compliance management service such as application **120** can advantageously enable rapid event intervention or enforcement of compliance violations.

HVAC management application **122** can control HVAC system **114** and lighting system **115** using, e.g., information from access control system **108**, video surveillance system **110**, or intrusion system **112**. Integrated control of HVAC system **114** can provide for improved occupant comfort or to conserve energy (e.g., based on occupancy information provided by access control system **108**).

Security management application **124** can provide a unified interface for monitoring security in a building space using a number of different inputs from a number of different subsystems. For example, security management application **124** can receive inputs from intrusion system **112**, video surveillance system **110**, access control system **108**, and/or HVAC system **114** (occupancy sensors of the HVAC system may be used by security algorithms of security management application **124**).

Integration server **102** is configured to allow for cross-subsystem data communication, for one of the applications of applications **106** to utilize data from more than one subsystem **104**, or for applications **106** to share information. More particularly, integration server **102** is intended to provide a messaging framework that can be understood by a plurality of applications regardless of the protocol or source of the subsystem information. Integration server **102** is further configured to provide a querying service that allows subsystems or applications to conduct cross-subsystem queries. Such cross-subsystem queries may allow an application (or end user operating the application) to utilize natural language queries or context rich queries. For example, a query such as the following may be entered by a user and executed by an application: "Show me high priority notifications about temperature increases outside of comfort levels in the rooms in the executive suite while the rooms in the executive suite are occupied." Such cross-system queries have traditionally been very difficult for end-users to create and execute without detailed information about the underlying database design and access to a low level query editor (e.g., a structured query language (SQL) editor).

Referring now to FIG. **2**, another block diagram of BAS **100** is shown, according to an exemplary embodiment. In FIG. **2**, BAS integration server **102** is shown in greater detail to include processor **200**, memory **202**, and communications electronics **204**. According to an exemplary embodiment, processor **200** can be implemented as a general purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable electronics components. Memory **202** (e.g., memory unit, memory device, storage device, etc.) is one or more devices for storing data and/or computer code for completing and/or facilitating the various processes described in the present disclosure. Memory **202** may be or include volatile memory or non-volatile memory. Memory **202** may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present disclosure. According to an exemplary embodiment, memory **202** is communicably connected to processor **200** via electronics circuitry and includes computer code for executing (e.g., by processor **200**) one or more processes described herein. Communications electronics **204** can be or include wired or wireless interfaces (e.g., jacks, antennas, transmitters, receivers, transceivers, wire terminals, etc.) for conducting data communications with another system or network. For example, communications electronics **204** can include an Ethernet card and port for sending and receiving data via an Ethernet-based communications network. In another example, communications electronics **204** includes a WiFi transceiver for communicating via a wireless communications network. Communications electronics **204** may be configured to communicate via local area networks or wide area networks (e.g., the Internet, a building WAN, etc.). While FIG. **2** shows applications **106** and subsystems **104** communicating with BAS integration server **102** via communications electronics **204**, in some embodiments applications **106** or subsystems **104** may be hosted within BAS integration server **102**. For example, BAS integration server **102** or, more particularly, memory **202**, can include HVAC management application **122** as well as many software components of HVAC system **114**.

Referring still to FIG. **2**, applications **106** are shown to include application adapters **206** and subsystems **104** are shown to include subsystem adapters **208**. Further, memory **202** is shown to include applications interface **210** and subsystems interface **212**. Integration server **102** is configured to receive messages transmitted from subsystems **104** and intended for reception by any other subsystem or for any of applications **106**. Messages normally transmitted from subsystems **104** can be formatted according to a particular subsystem protocol (proprietary or standardized). Subsystems interface **212** may be configured to receive messages from subsystems **104** and to convert the messages from the particular subsystem protocol into an integration protocol intended for consumption and use by integration server **102**. The "integration protocol" is the native protocol of BAS integration server **102**. Accordingly, adapters **206**, **208** or interfaces **210**, **212** operate to resolve syntactic-type heterogeneities (as opposed to semantic-type heterogeneities) that may exist between a received message and the integration protocol.

Some of applications **106** or subsystems **104** may be configured to communicate via the integration protocol without protocol conversion. As shown, adapters **206**, **208** for conversion may be included with applications **106** or subsystems

104 (e.g., if the application developer supports such adapters or builds such an adapter into the application). In other instances the protocol conversion may be handled by interfaces 210, 212 of BAS integration server 102. For example, if a subsystem does not include an adapter 208 of its own and transmits proprietary messages to BAS integration server 102, subsystem interface 212 can receive such messages and convert the messages into communications according to the integration protocol. An adapter or interface for conducting conversion into an integration protocol may be provided for each different application protocol or subsystem protocol to be consumed by BAS integration server 102. When an application or subsystem has an adapter and conducts its own conversion to the integration protocol, applications interface 210 or subsystems interface 212 may allow the message to pass through to further components unmodified.

Referring further to FIG. 2, BAS integration server 102 is shown to include a semantic mediator 214. Semantic mediator 214 is generally configured to resolve semantic heterogeneities between a subsystem or application and BAS integration server 102. Semantic heterogeneities may occur in resource naming, resource hierarchy properties associated with a resource, actions that may be performed by an actionable resource, and the like. Semantic mediator 214 is described in greater detail in subsequent Figures. Data or messages converted into an integration protocol are made semantically complete by semantic mediator 214. Semantically complete messages may be stored in multi-purpose data storage and indexing engine 216 or transmitted to other subsystems or applications via rules contained in workflow engine 218. For example, when occupancy information is received from a security subsystem (e.g., access control subsystem 108 shown in FIG. 1) it may be processed by semantic mediator 214 and provided to workflow engine 218 which may use a set of rules to determine that the semantically unified occupancy information is to be further provided to an HVAC subsystem, a security interface, and an HVAC application.

Referring now to FIG. 3, a detailed diagram of semantic mediator 214 is shown, according to an exemplary embodiment. Semantic mediator 214 includes and utilizes ontology database 300 to conduct its conversions. Ontology database 300 stores sets of resource definitions and relations between resources. Ontology database 300 may initially be populated and maintained via ontology editor 302. Ontology editor 302 may generate graphical user interfaces (GUIs) for display on a connected (e.g., networked) electronic display device or remote terminal. Ontology editor 302 may be used to model a theoretical BAS via a relational database. The model of a theoretical BAS may be represented (e.g., via a GUI presented to a system engineer) using a directed graph such as shown in FIG. 4A. Ontology editor 302, another computer process, or a manual process may be used to convert the directed graph of FIG. 4A into a hierarchical model of a theoretical building automation system by creating the table set of FIG. 4B. Reading the table "Is_A_Kind_Of", one can see, for example, that Analog Input (concept "4") is a kind of Analog Device (concept "3"), which is a kind of Device (concept "2"). Further, Analog Input (concept "4") has attributes 3, 4, 5, and 6 which correspond to Device_Type, Present_Value, Out_Of_Service, and Units attributes. By fully populating ontology database 300 with a hierarchical model of a building automation system, semantic mediator 214 provides a hierarchical model or reference for applying to or for use by a particular BAS. However, ontology database 300 does not store particular instances of BAS configuration data or data relating to a particular set of BAS subsystems. Rather, ontology database 300 provides the logical model (e.g., theoretical model, hierarchical model, reference model, etc.) for a particular BAS and its configuration data. Particular configuration data, as well as actual recent state information and values, are stored in fact database 304. Aspects of fact database 304 are based on the model of ontology database 300. For example, the hierarchical model of ontology database 300 may be used to fully populate information of fact database 304. FIG. 5A illustrates a particular application of the ontological model (i.e., hierarchical model) shown in FIG. 4A to a device named "Therm 03FL EW." Each attribute is populated with a value. Using the directed graph shown in FIG. 5A, a person can view and appreciate the context relating to any given attribute (e.g., Present_Value:"66.23") by inspecting surrounding attributes and traversing through the graph to learn more about the type of device to which the attribute relates.

Fact Database

To enable fast information retrieval and to reduce the number of tables that must be accessed during a query operation, fact database 304 may be configured to store information in at least one table having a flat format. Such a table may include one row per attribute (e.g., one row per BAS attribute, one row per BAS object) in a complete BAS (including all of the BAS subsystems). In an exemplary embodiment, each row or record is stored with a projected semantic type string comprising multiple levels of type information and based on the hierarchical model stored in the ontology database 300. By way of example, FIG. 5B is a simplified example of a fact database 304 portion having contents representing the device of FIG. 5A and using the ontological model stored in the tables of FIG. 4B. A query for the value for Present_Value of Device "Therm 03FL EW" should provide the row having a logical type "1→2→3→4#Present_Value" as well as an instance value of "66.23." Therefore, in addition to the actual value or instance value (i.e., "66.23"), the return string includes a projection of the semantic type information relating to the actual value or instance value. In the example of FIG. 5B, the projected semantic type string includes the name of the attribute (the string after "#") as well as the attribute's parent device (e.g., the "4" prior to the "#") and a projection of further hierarchical information. The projected semantic type string can be parsed (e.g., by the semantic mediator, by another application, etc.) to obtain semantic information such as an attribute's full type hierarchy. Multiple records in the fact database can be used to construct, re-construct, or use the information of the directed graph of FIG. 5B. Advantageously, normal accesses to the Fact DB may not require multiple table accesses, queries that join multiple tables, or other more complicated queries to return and use the fully projected semantic type information. For example, using the projected semantic type information returned in the logical type field, a receiving node (e.g., having ontology information, configured to understand the delimiters and string contents of the projection, etc.) can determine that the attribute "Present_Value" is an attribute of "Analog Input," that "Analog Input" is a kind of "Analog Device," and that "Analog Device" is a kind of "Device." Each relationship in the projected semantic type string may be delimited with a different character or set of characters. In the example of FIG. 5B, "→" represents the Is_A_Kind_Of relationship and "#" represents the Has_Attribute relationship. In an exemplary embodiment the projected semantic type string is fully projected (e.g., each semantic type string begins at a root node and communicates all intermediate relationship information between the root node and the particular object or attribute of the record). In other exemplary embodiments the projected semantic type

string is not fully projected and starts with a logical head node (e.g., a field controller associated with the object). In some embodiments, a fact database may use multiple tables to represent multiple different types of relationship hierarchies. In other embodiments the fact database may include fewer tables (e.g., a single table).

The projected semantic type information of fact database **304** may also contribute to the ability of BAS data to be indexed and quickly retrieved via the index. Devices in a BAS subsystem may most frequently transmit messages by a subsystem specific data type or unique name string. These unique subsystem specific type strings normally transmitted by the BAS subsystems to the integration server may be the keys used to create indexed hash values for the Fact DB. Therefore, when a message is received from a subsystem its type may be used to quickly access the corresponding record in the fact database and the projected semantic type information may be extracted from the record without joining another table. This projected semantic type string may be appended to the message from the BAS subsystem and quickly forwarded to an application or another process for consumption. This process may facilitate fast retransmission of messages via the integration server generally and the semantic mediator more particularly. Once retransmitted the messages include hierarchical information (e.g. the projected semantic type string) so that the consuming processes can process the message in light of the rich context provided by the projected semantic type information.

FIG. **5**D illustrates a process for providing messages from disparately protocolled building automation subsystems **104** to applications **106** that use an integration protocol. Messages transmitted through subsystem adapters **208**, communications electronics **204**, and subsystems interface **212** may be variously reformatted, cleaned, or parsed, but semantic mediator **214** still receives information that has not yet been fully converted from a subsystem specific protocol to a context rich message. In an exemplary embodiment the messages from subsystems interface **212** include a subsystem specific type string. In some embodiments the subsystem specific type string may be changed or added to the message by the subsystems interface **212** or subsystem adapters **208**. A hash function of messaging engine **308** may resolve received subsystem specific type strings into indexed hash values existing in Fact DB. The messaging engine **308** may use the indexed hash values to quickly retrieve logical type and instance value information corresponding to the subsystem hashed index value. The messaging engine **308** may update the "instance value" field based on a changed value in the subsystem message. The messaging engine **308** may then transform the subsystem message into a standard format and append the logical type string (e.g., a fully projected semantic type string, a partially projected semantic type string, a hierarchical type string, a flat string that describes a type hierarchy, etc.) to the transformed message. The messaging engine **308** can then provide the message to the applications interface **210** which may coordinate the transmission of the message via communications electronics **204** to application adapters **206** and applications **106**.

In other exemplary embodiments the Fact DB may have multiple indexes or use a hash index that has multiple inputs. For example, because particular types of devices may be well distributed around a building, one or more of the hash functions used to create index values may be based on a location-based relationship. For example, if Served_By is a relationship that is tracked by the system and generally describes an area (e.g., a floor) that is served by a device or system, fact database **304** may include a logical type entry such as "1→Floor 4A→2→3→4#Present_Value." Accordingly, "Floor 4A" may be hashed as a key (or used as one of many inputs to a hash function) to allow for faster location-based searching or querying. It should be appreciated that other indexing schemes may be utilized to search the records of fact database **304**. The indexing may be completed using, e.g., multi-purpose data storage and indexing engine **216** shown in FIGS. **2** and **3**.

To build fact database **304** or to add records to fact database **304** as devices are brought online, multi-purpose data storage and indexing engine **216** may be configured to utilize a type concatenation process that traverses from the relationship root (ϕ) in the tables shown in FIG. **4**B to each child node. The concatenation process recursively adds names or values to the projected semantic type strings of fact database **304**. For example, when fact database **304** is initially being populated, a process may start at the root, add the root to the string, get the first record in the "Is_A_Kind_Of" table, add "2" to the string delimited by a character that represents the "Is_A_Kind_Of" relationship, and so on.

Referring still to FIG. **3**, semantic mediator **214** is shown to include a concept alignment tool **303** and a fact builder **305**. Concept alignment tool **303** provides a user interface to a user for customizing the conversion from a proprietary message into a standardized integration protocol message. For example, concept alignment tool **303** allows users to create functions or scripts for recognizing a piece of data having a first protocol or format and converting the data into the integration protocol message. Fact builder **305** provides a user interface to a user for applying the ontology relationships to a particular BAS and for recording relationships that automated processes of the system have difficulty recognizing or recording. For example, some of the relationships of fact database may be concepts relating to user organization of a space. A space-related relationship of ontology database may be "serves" and another may be "located_within." The "serves" relationship may relate the services provided by a building device to a particular building space or spaces. The "located_within" relationship may relate a building device to its particular location or locations. The fact builder **305** may provide a user with a graphical user interface for associating a number of locations with the "serves" and "located_within" relationships. For example, the fact builder **305** may associate a single thermostat with multiple rooms using the "serves" relationship and with a single room using the "located_within" relationship.

The process for building the BAS integration framework (e.g., the contents of the fact database) disclosed herein may be manual (e.g., driven via user interfaces of concept alignment tool **303** or fact builder **305**), automated (an automated configuration module may use inferences, patterns, and test signals to create and refine BAS integration data), or a mixture thereof. The process **500** of FIG. **5**C is an exemplary process for building a BAS integration framework regardless of whether the process is manual, fully automated, or a mixture thereof. Process **500** includes reading configuration data from a building site (step **501**). Step **501** can include learning as much information about the current site and the site's disparate subsystems as possible and obtaining all of the inputs and outputs of the system for relation, tagging, or classification. Step **502** includes creating and storing a normalized data set for the site based on the read configuration data. Step **502** may include, for example, creating a list of devices to be classified and related. Step **503** includes transforming the normalized data set into semantic type hierarchy and relationship information. Step **503**, for example, may include building an ontology database using the data retrieved

and stored in steps **501** and **502**. Step **503** may also include the population of tables in the fact database or other classification of devices and inputs or outputs. Process **500** further includes generating a detailed table of properties and actions for the BAS site based on the hierarchy and relationship information (step **504**). The detailed table of properties may be, for example, the fact database shown in FIG. **5**B. An index for the detailed table may be created (step **505**) using a hashing function based on, for example, corresponding subsystem-specific information (e.g., a subsystem specific type string), the hierarchy information, or the relationship information. For example, a subsystem-specific string that will be transmitted to the integration server from the subsystem may be applied to a hash function and the results may be used in the indexing of the Fact DB (see, e.g., FIG. **5**B, FIG. **5**D).

Query Processing and Integrated Event Monitoring

As mentioned above, the architecture of BAS integration server **102** generally and semantic mediator **214** more particularly can be used to provide for rich querying services. One example of such a service is a subscription service wherein an application (GUI application) subscribes to receive events within the subsystems. As subscribed events occur in the subsystems, messages are generated and sent to the client. For example, a GUI may allow a user to create a subscription query using natural language such as:

Q0="Receive priority notifications about temperature increases outside comfort levels in the executive offices area while any of the executives are there."

As indicated above, such a query may be resolved by accessing two subsystems (e.g., an HVAC system and an access control system). The natural language aspects of query Q0 are transformed into semantics usable by subsystems (e.g., using the semantic mediator, using pre-stored rules and policies). One exemplary process **600** for receiving and servicing a subscription based on a query such as Q0 is shown in FIG. **6**A. Query Q0 may first be parsed to recognize or separate verbs and conditions (step **601**). An integrated query may then be built using the recognized verbs and conditions (step **602**). The integrated query may be built by, for example, changing the recognized verbs and conditions to standardized terms and conditions. The system may then determine whether the integrated query requires information from two or more subsystems (step **603**). If the query requires two or more subsystems, process **600** may then decompose (i.e., separate) the integrated query into subsystem queries using concept mapping provided by the fact database (step **604**). Examples of such concept mapping are provided below in FIG. **6**B. Once such subsystem queries are created and concept mapped, the system may wait for return values meeting the query requirements from the subsystems (step **605**). Even when a subsystem query yields a positive result (returns more than an empty set for a given period of time), the system may then determine if all of the conditions of the integration query are met (step **606**). For example, the system may determine whether both subsystem queries yielded results corresponding to a similar period of time (if the query is temporal) or are otherwise appropriately joined. If all of the conditions of the integration query are met, the return information is provided to the user or subscription (step **607**).

FIG. **6**B illustrates the concept mapping tables that may be stored in a fact database. Table 6-1 associates location names with location IDs. Table 6-2 contains a hierarchy of locations where the table associates a parent location ID with a location ID. Each location ID may be a constructed by concatenating the parent ID with the particular location ID. Table 6-3 maps locations (e.g., rooms) to points from the control system. In Table 6-4, tags are applied to the location entities.

FIG. **6**C illustrates four queries that may be used to process the HVAC subsystem query. Because the HVAC system may not store concepts such as location information, room type information and the like (or in systems wherein multiple HVAC systems are used), the system refers to multiple concepts in the ontology database or the fact database to seek the correct information from the subscription. Particularly, the queries shown in FIG. **6**C find points to monitor in Q2 by querying Table 6-1, 6-2, and 6-3 in an iterative fashion. Query Q1.1 finds all locations where the tag is equal to "Executive." This query will return rooms and floors. If a particular room has not been tagged with "Executive" but the entire floor in which a room exists has been tagged with "Executive" then Query Q1.2 will catch this inheritance. Query Q1.3 finds all HVAC points where the point name includes "ZN-T" (which may indicate a temperature sensor). Q2 queries an events table (which may be a table of recent events) where the point is identified by Q1.3, the event priority is greater than 40, and the temperature indicated by the event is greater than a comfort limit. The system may convert "high priority" from Q0 into the numeral 40 via a lookup table in the ontology database or otherwise.

The creation of queries Q1.1 through Q2 or portions thereof can be completed manually and the queries or query templates may be stored in memory. Referring now to FIG. **6**D, when a user or application requests that a complete query Q0 be executed, query engine **306** may use a table **640** of transformation sequences or logic to build a transformation sequence **642** (i.e., a sequence of queries expected to be responsive to Q0). For example, Q0 may be a pre-established string that a user or application may select for execution. Query engine **306** can lookup transformation sequence **642** and drive the sequential execution of Q1.1, Q1.2, Q1.3, and Q2. The table of transformation sequences 640 may include links to queries Q1.1, Q1.2, Q1.3, and Q2 along with an indication of the order or nesting for the queries. One or more of the stored queries (e.g., Q1.1) can include variables for user population. For example, the "Executive" may be replaced with a variable that describes a tag or set of tags to be searched. Accordingly, any query that includes a spatial requirement (e.g., "executive area", "classroom", etc.) can use or reuse the Q1.1 and/or Q1.2 structure.

Referring now to FIG. **6**E, a process **650** for implementing a cross-subsystem command is shown, according to an exemplary embodiment. Process **650** is shown to include receiving a command at an integration server (e.g., integration server **102**) from an application (e.g., one of applications **106**) (step **651**). The command may be, for example, a user interface driven command to "lower temperature in all occupied offices by five degrees." The integration server may then provide the command to a workflow engine (e.g., workflow engine **310** shown in FIG. **3**) (step **652**). The workflow engine may then lookup a process for responding to the command using a rules and policies database (e.g., rules and policies database **311**) (step **653**). The rules and policies database may include a process such as: a) find all occupied building spaces using network connection information or occupancy sensor information; b) find all temperature subsystem setpoints associated with the identified occupied building spaces; c) lower setpoint temperatures by X percent. The workflow engine can then step through the process by using the query engine (step **654**). Step **654** can include finding cross-subsystem command points (e.g., a setpoint attribute that may be changed for a first HVAC subsystem, an object method for changing temperature in a second HVAC subsystem, etc.). The query engine can use the fact database or the ontology database to conduct such queries. Process **650** further includes, at the

workflow engine, using the identified cross-subsystem command points and the rules and policies database to generate separate subsystem-specific commands (step **655**). For example, the rules and policies database may store conversions from a percentage scale to scales particular to the subsystems that will be commanded. A five percent reduction, therefore, may be commanded in a first HVAC subsystem by using a number of TempPercReduction(5) commands and in a second HVAC subsystem by converting 5% to 1.5 steps on a 30 point scale. Once the separate commands are provided to the subsystems, the semantic mediator is used to receive and parse return values received from the particular building automation subsystems (step **656**). The semantic mediator provides the return values to the workflow engine, which may track the return conditions (step **657**). By tracking the return conditions from a plurality of subsystems using the semantic mediator, the system can understand when the process is complete, providing feedback to the user at a graphical user interface of the command-originating application.

Additional Features of the Messaging Engine

Referring back to FIG. **3**, when messages are received by semantic mediator **214**, they are processed by messaging engine **308**. The messages may be received in response to user initiated queries or subscriptions as described above. When a message is received, workflow engine **310** may be configured to determine whether the message is expected by a subscription or query. For example, workflow engine **310** may be configured to route information regarding occupancy in a space to multiple different applications, processes or queries waiting for such an update. Even if workflow engine **310** determines that no subscriptions or queries are waiting for information in a received message, messaging engine **308** may transform the message and provide the transformed message to multi-purpose data storage and indexing engine **216** for archival. Regardless of the recipient of the message, messaging engine **308** may add context information (e.g., a projected semantic type string) into an incoming message as well as standardize items such as events, date/time, and identifiers. An example of a messaging transformation conducted by messaging engine **308** is shown in FIG. **7**A. The variables and the values of the received access control subsystem message are not well described, resolved, or have context. The lower box illustrates a message fully mediated by semantic mediator **214** and messaging engine **308**.

The process **750** utilized by messaging engine **308** to achieve the transformation shown in FIG. **7**A is illustrated in FIG. **7**B. Process **750** is shown to include receiving the access subsystem message (step **702**) and transforming the message into an integration protocol compliant message (step **704**). This basic transformation can be accomplished by, e.g., converting the format of the received access control subsystem message to a format compliant with the integration protocol. In the example shown in FIG. **7**A, the integration protocol is an XML-based protocol. In other embodiments other data messaging protocols may be used. Process **750** further includes matching the resultant integration protocol compliant message contents to content in the fact database (step **706**). For example, "sb_EventType 23" may correspond with "AccessSystem→Door@Access_granted" in the fact database, the ontology database, or another lookup table. In one example the subsystem specific type "sb_EventType 23" is applied to a hash function to lookup an index location in the fact database. Hierarchical information (e.g., a projected semantic type string) of the identified content in the fact database can then be utilized to inherit mediated attributes (step **708**). For example, the system may use the event type of "AccessSystem→Door@Access_granted" to retrieve more information about the access system door (e.g., who caused the event, and information about the particular access panel associated with the door). This information can be appended to the integration protocol compliant message (e.g., in addition to the projected semantic type string) to populate the integration compliant message (step **710**). For example, CardHolderInfo and AccessPanel information may be retrieved from the fact database using, e.g., the event ID and the event type.

The construction and arrangement of the systems and methods as shown in the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.). For example, the position of elements may be reversed or otherwise varied and the nature or number of discrete elements or positions may be altered or varied. Accordingly, all such modifications are intended to be included within the scope of the present disclosure. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes, and omissions may be made in the design, operating conditions and arrangement of the exemplary embodiments without departing from the scope of the present disclosure.

The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure may be implemented using existing computer processors, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

Although the figures may show a specific order of method steps, the order of the steps may differ from what is depicted. Also two or more steps may be performed concurrently or with partial concurrence. Such variation will depend on the software and hardware systems chosen and on designer choice. All such variations are within the scope of the disclosure. Likewise, software implementations could be accomplished with standard programming techniques with rule based logic and other logic to accomplish the various connection steps, processing steps, comparison steps and decision steps.

What is claimed is:

1. A computer-implemented system for facilitating cross-subsystem queries of a plurality of building automation subsystems, comprising:

an ontology database storing an ontological model for a building automation system (BAS), wherein the ontological model defines multiple different BAS object types, relationships between the BAS object types, and attributes of the BAS object types;

a fact database storing instance values for the plurality of building automation subsystems and a logical type for each of the stored instance values, wherein the logical type identifies a particular attribute of the ontological model described by the stored instance value and represents, in a flat format, a portion of the ontological model that provides semantic type information for the stored instance value; and

a query engine configured to decompose a cross-subsystem query received from an application into a plurality of subsystem queries using information of the fact database, wherein the query engine parses the logical types in the fact database to obtain the semantic type information for the stored instance values and uses the obtained semantic type information to identify one or more of the stored instance values relevant to the cross-subsystem query without requiring access to another database.

2. The computer-implemented system of claim 1, wherein the logical type is a text string comprising:

multiple different type indicators representing the multiple different BAS object types; and

delimiters representing the relationships between the BAS object types.

3. The computer-implemented system of claim 1, wherein the query engine utilizes the fact database to determine ordering for the subsystem queries.

4. The computer-implemented system of claim 1, wherein the query engine retrieves the subsystem queries from sets of pre-built and pre-stored subsystem queries.

5. The computer-implemented system of claim 1, wherein the query engine builds the subsystem queries by processing the cross-subsystem query.

6. The computer-implemented system of claim 1, wherein the query engine stores the plurality of subsystem queries and provides an updated message to the application originating the cross-subsystem query when results of the cross-subsystem query change.

7. The computer-implemented system of claim 6, wherein the query engine provides the changed results through a messaging engine that uses the query result to build a message for the application.

8. The computer-implemented system of claim 6, wherein a messaging engine appends semantic type information from the fact database to the message for the application.

9. The computer-implemented system of claim 8, wherein the message for the application includes at least one of the logical types representing the semantic type information associated with the message contents and based on the ontological model of the first database.

10. The computer-implemented system of claim 1, wherein the plurality of disparate building systems comprise a first heating, cooling or air-conditioning (HVAC) system, a second HVAC system, an access control system, and a security system.

11. The computer-implemented system of claim 1, further comprising:

one or more sensors configured to measure a variable state or condition within a building space, wherein at least one of the stored instance values is provided by the one or more sensors;

a controller configured to generate a control signal using information provided by the one or more sensors; and

one or more BAS devices configured to receive the control signal from the controller and to affect the measured variable state or condition by operation of the BAS devices.

12. A computer-implemented method for facilitating cross-subsystem queries of a plurality of building automation subsystems, comprising:

receiving a cross-subsystem query from an application;

accessing a fact database that stores instance values for the plurality of building automation subsystems and a logical type for each of the stored instance values, wherein the logical type identifies a particular attribute of an ontological model described by the stored instance value and represents, in a flat format, a portion of the ontological model that provides semantic type information for the stored instance value;

parsing the logical types in the fact database to obtain the semantic type information for the stored instance values;

using the obtained semantic type information to identify one or more of the stored instance values relevant to the cross-subsystem query without requiring access to another database;

recognizing that the identified instance values are provided by more than one of the plurality of building automation subsystems; and

decomposing the cross-subsystem query into a plurality of subsystem queries using information from the fact database.

13. The computer-implemented method of claim 12, further comprising:

determining ordering for the subsystem queries using information from the fact database.

14. The computer-implemented method of claim 12, further comprising:

retrieving the subsystem queries from sets of pre-built and pre-stored subsystem queries.

15. The computer-implemented method of claim 12, further comprising:

building the subsystem queries by processing the cross-subsystem query.

16. The computer-implemented method of claim 12, further comprising:

storing the plurality of subsystem queries and providing an updated message to the application originating the cross-subsystem query when results of the cross-subsystem query change.

17. The computer-implemented method of claim 16, further comprising:

providing the changed results to a messaging engine that uses the query result to build a message for the application; and

appending the semantic type information from the fact database to the message for the application.

18. The computer-implemented method of claim 17, wherein appending the semantic type information includes appending at least one string comprising the logical type associated with the message contents;

wherein the string is a projected semantic type string relating to the subsystem type of the message contents.

19. The computer-implemented method of claim 12, wherein the plurality of building automation subsystems comprise a first heating, cooling or air-conditioning (HVAC) system, a second HVAC system, an access control system, and a security system;

wherein the plurality of building automation subsystems are disparately protocolled.

20. The computer-implemented method of claim 12, further comprising:

measuring a variable state or condition within a building space using one or more sensors, wherein at least one of the stored instance values is provided by the one or more sensors;

generating a control signal at a controller using information provided by the one or more sensors; and

operating one or more BAS devices configured to affect the measured variable state or condition using the control signal from the controller.

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